

Summary Statistics for LC_TA03_130719: Micro-CT Data Acquired at LLNL, Specimen 3 of 3

Isaac M. Seetho, Stephen A. Strout,
W. Travis White, III, Harry E. Martz, Jr.
Lawrence Livermore National Laboratory
Livermore, CA 94551

Work performed on the
Science & Technology Directorate of the
Department of Homeland Security
Statement of Work
HSHQPM-10-X-00005 P00007

December 13, 2013
LLNL-TR-655003



This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Executive Summary

LC_TA03_130719				
Measured Density: 0.72 g/cm ³		X-ray tube voltages (source filter materials)		
Parameter		μ_L 100 kV(Al), Al-BHC	μ_L 100 kV(Al), H ₂ O-BHC	μ_H 160 kV (AlCu)
LAC	Mean Measured LAC (LMHU) ¹	912	937	639
	Standard Deviation/Mean	8%	7%	9%
	Entropy	5.71	5.58	5.48
^L Z _{eff}	From the mean measured LACs	7.58		
^{LW} Z _{eff}	From the mean measured LACs	7.22		
μ_L/μ_H	Using Al-BHC	1.43		
μ_L/μ_H	Using H ₂ O-BHC	1.47		
QA	From Cu strip and References	See p.5		

Table 1. First-order statistics of the x-ray linear attenuation coefficient (LAC) in LC_TA03_130719, the estimated value of the effective atomic number, Z_{eff} [1] and μ_L/μ_H . Z_{eff} is calculated from the ratio of μ_L/μ_H . Beam hardening compensation has been applied to μ_L using both aluminum (^LZ_{eff}) and water (^{LW}Z_{eff}) beam hardening parameters.

Using x-ray micro computed tomography (MicroCT), we have characterized the linear attenuation coefficients (LAC), μ , of a sample of a dry powder material, lithium carbonate (LC). The specimen was prepared at Lawrence Livermore National Laboratory (LLNL), loaded into a 60mL low density polyethylene (LDPE) bottle. After completed packing, the specimen was scanned following the protocol for MicroCT measurements under Test Plan 79 [2].

This particular specimen, LC_TA03_130719, recorded the bulk packing density (mass of sample divided by volume of sample) shown above. Two additional preparations were made and analyzed [3-4]. We used the computer program IMGREC to reconstruct the CT images. The values of the key parameters used in the x-ray data capture and image reconstruction are given in this report. Additional experimental details may be found in the SOP [5] and a separate document [6]. To characterize the statistical distribution of LAC values in each CT image, we first isolated an ~80% region or segment of volume elements (“voxels”) lying completely within the sample, away from the walls of the container. We then calculated the mean value, standard deviation and entropy for (a) the high and low energy image segments and for (b) their digital gradient images². The statistics of the initial image of LAC values are called “first order statistics;” those of the gradient image, “second order statistics.” See Seetho [7] for details of the analysis used to obtain the numbers reported in this document.

¹ LMHU: “LLNL modified Hounsfield units with respect to water.” To obtain the LAC in LMHU for some material at any energy, we multiply by 1000 and divide by the LAC of water at an x-ray energy of 160 kV with aluminum and copper filters.

² A digital gradient image of a given image was obtained by taking the absolute value of the difference between the initial image and that same image offset by one voxel horizontally, parallel to the rows of the x-ray detector array.

Summary of LC_TA03_130719 X-ray Statistics**Report Date:** December 13, 2013**Report Prepared by:** Isaac Seetho
*Typed or Printed Name***LLNL**
*Organization***QA:** Isaac Seetho
*Typed or Printed Name***LLNL**
*Organization***Material ID(s):** LC_TA03_130719

Source			Collimator	Beam Hardening	Sample Preparation	X-ray Measurement	Linear Attenuation Coefficient (LAC)							
Bias (kV)	Filters		Number of slits	Parameter Source	Date	Date	Statistic	1 st order	2 nd order					
	Material	Thickness												
100	Al	1.943 mm	2	H ₂ O	7/3/2013	7/19/2013	Mean	937	57					
							Std. Dev.	64	43					
							Entropy	5.58	5.02					
100	Al	1.943 mm	2	Al	7/3/2013	7/19/2013	Mean	912	61					
							Std. Dev.	73	46					
							Entropy	5.71	5.09					
160	Al Cu	1.943 mm 1.905 mm	2	None	7/3/2013	7/19/2013	Mean	639	53					
							Std. Dev.	58	40					
							Entropy	5.48	4.94					
^L Z _{eff}	Based on measured LAC (Al-BHC)							7.58						
^{LW} Z _{eff}	Based on measured LAC (H ₂ O-BHC)							7.22						
μ_L/μ_H	Based on measured LAC (Al-BHC)							1.43						
μ_L/μ_H	Based on measured LAC (H ₂ O-BHC)							1.47						

Table 2. Key statistics [8] for x-ray measurements of Linear Attenuation Coefficient (LAC). ${}^L Z_{eff}$ is determined from 100 kV (Al) to 160 kV (AlCu) LAC (μ_L/μ_H) as given in reference [1]. The statistics here are from the 2-slit image data (not the 1-slit open image data).**Comments:** _____

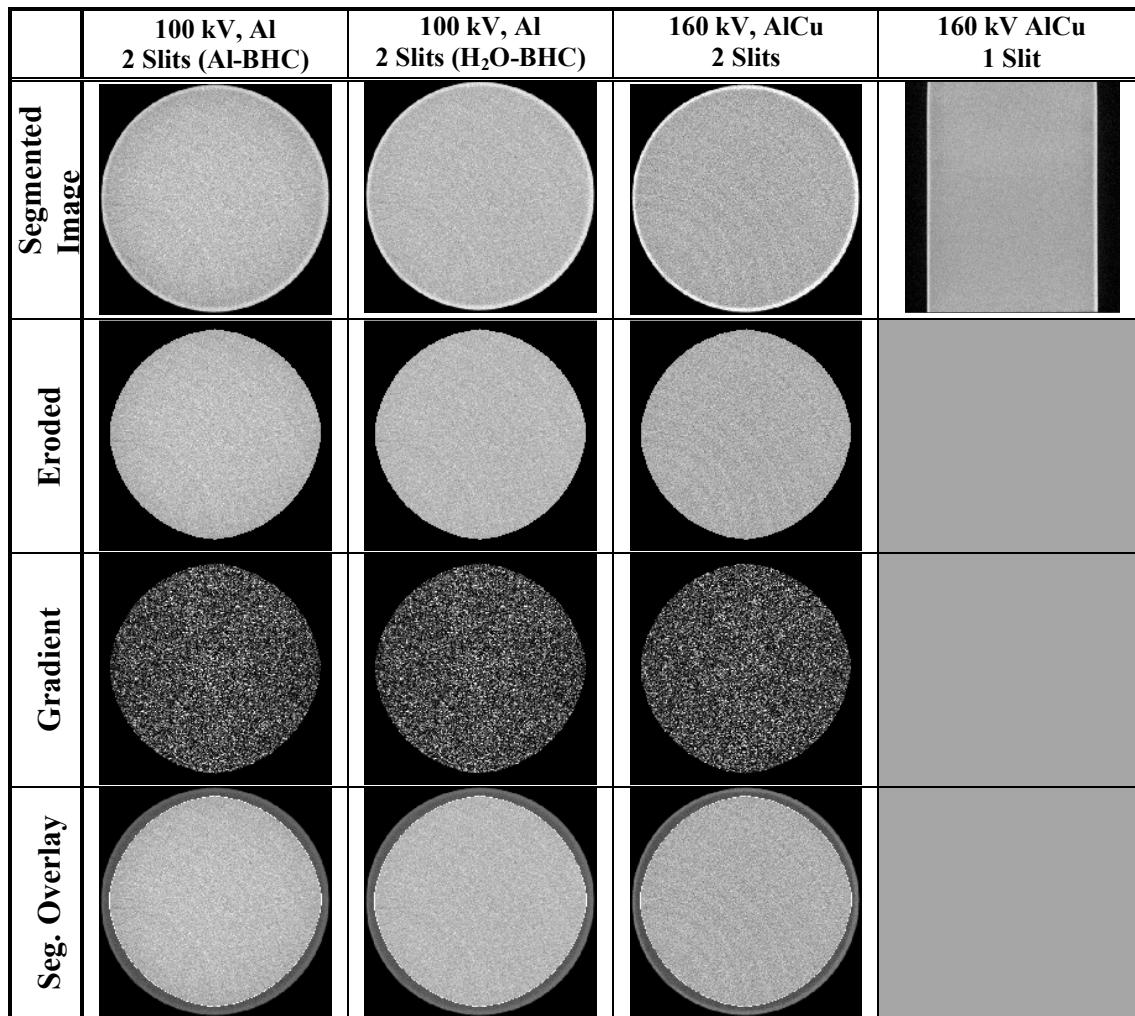


Figure 1. X-ray slice images with $150\mu\text{m} \times 150\mu\text{m} \times 150\mu\text{m}$ voxels. Raw data (top row), segmented images (second row), eroded images (third row) used to calculate first order statistics. Fourth row, difference or gradient image used for second-order statistics. Images not to scale and use different gray scales to obtain maximum contrast. Single slit images (top right) are used for a qualitative visual assessment of homogeneity.

Comments/Observations on Appearance of Sample (texture, color, other):

The specimen displays a uniform texture.

SUPPLEMENTAL ANALYSIS

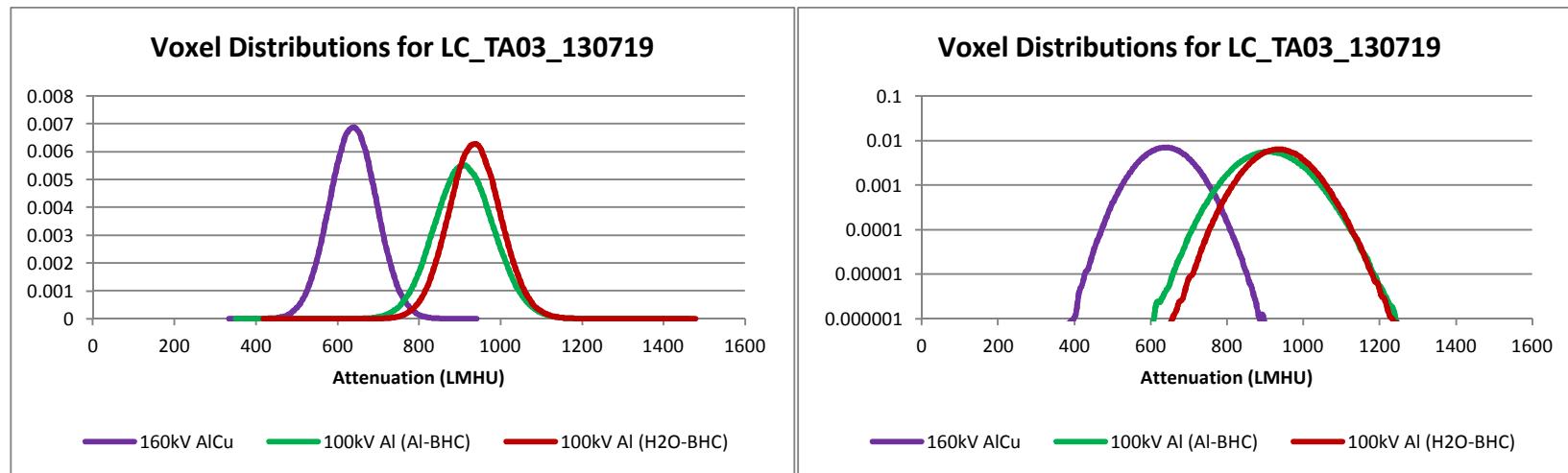


Figure 2. KDE histograms of values of the linear attenuation coefficient (LAC) for LC_TA03_130719 for two x-ray source settings (linear plots – left; semi-log plots – right).

Comments/Observations on Histograms: These histograms are made with a Gaussian Kernel Density Estimator (KDE) [8, 9] using 150- μm voxel upper-slit CT images.

Reference Specimens

	Parameter	graphite	ethanol	Delrin*	water	Teflon**	aluminum***
100kV, Al (Al-BHC)	Mean (LMHU)	1737	1036	1809	1410	3044	7001
	Std Dev LMHU	83	58	82	55	91	143
100kV, Al (H2O-BHC)	Mean (LMHU)	1851	1123	1940	1506	3173	6723
	Std Dev LMHU	78	58	76	55	67	233
160kV, AlCu	Mean (LMHU)	1395	805	1339	1000	1923	2957
	Std Dev LMHU	63	48	57	48	60	73

Table 3. Linear attenuation coefficients of six reference materials as measured simultaneously with LC_TA03_130719.

* Acetron® GP copolymer. **Enflo Corp. PTFE. ***T6061 alloy.

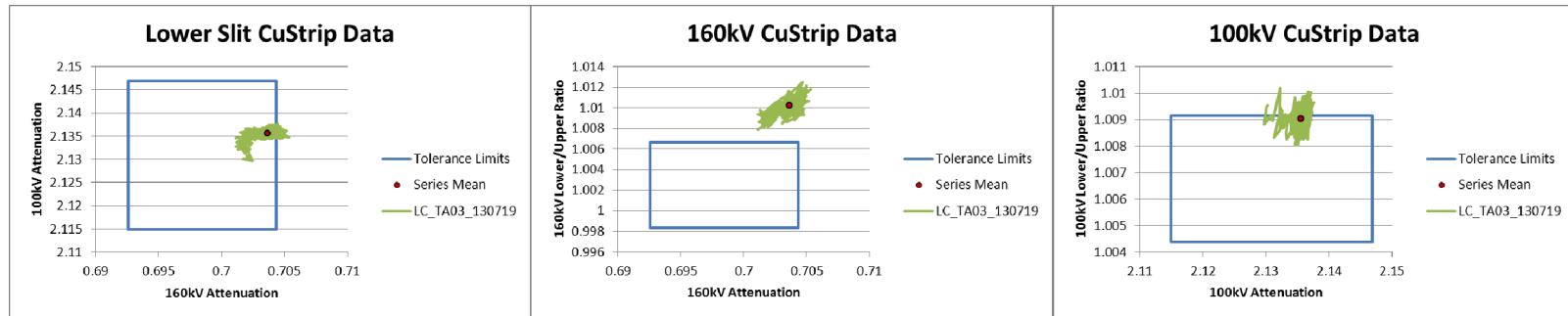


Figure 3. Copper strip ratio value for 160kV is above limits. These tolerance limits were defined using a set of scans spanning from April through May 2013.

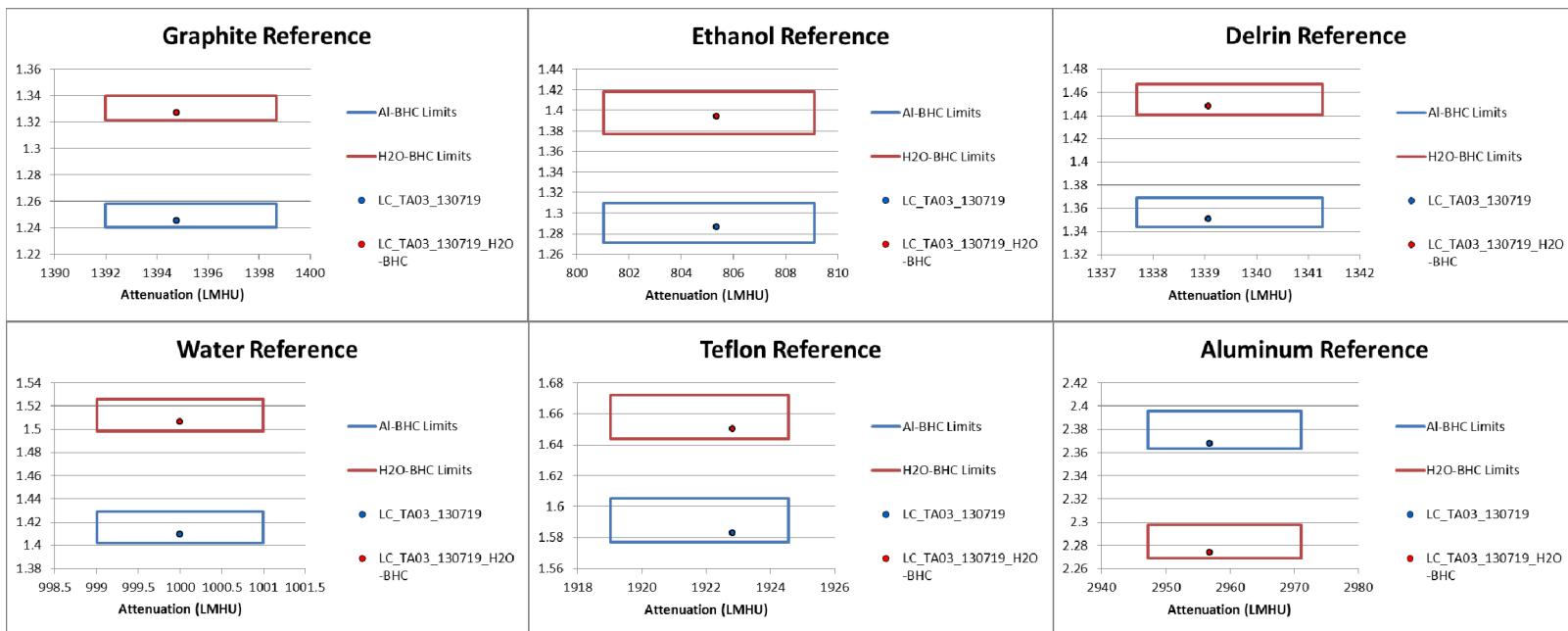


Figure 4. Reference materials are within the defined tolerance limits. These tolerance limits were defined using a set of scans spanning from April through May 2013.

Micro-CT System Configuration

1. Scan Location Site: LLNL HEAF
2. Source: Yxlon D09 450 kV Tube; Mfr. Catalog Number: 9421-172-33503; S/N 21-5204
3. Detector: Thales Flashscan 33 with Lanex Fine Gadolinium Oxysulfate Scintillator Screen; s/n 91106194
4. Rotation control system. Controller: Newport Model ESP7000 SN: 1250
5. Carousel: LLNL 2-tray, 6" Dia.
6. Data capture computer: Dell DHM/J4271

Micro-CT Scan Parameters

1. Scan Geometry:¹ SOD (mm): 1131.0 ODD (mm): 298.7
Number of positions: 400 Angular Range: 200° Angular Increment: 0.5°
2. Number of Frames averaged per Image: 4
3. Integration time per frame: See p 7.

¹ Distances are those recorded in the .sct file for this experiment and are the values used in image reconstruction.

File Storage Locations for X-ray Data Specimen

Root Data Path:

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\LC_TA03_130719\Test_Data\{sub directory}\

Specimen ID	Date	Radiographer	Slits	kV	mA	Al Filter (mm)	Cu Filter (mm)	Integration dpix Setting [time/frame (s)]	{sub directory}	File Name
LC_TA03_130719	130719	Strout	2	100	1.1	1.943	0	8 [2.8s]	LC_TA03_130719_100Al	LC_TA03_100Al_nn.sdt ¹
	130719	Strout	2	160	4.35	1.943	1.905	8 [2.8s]	LC_TA03_130719_160AlCu	LC_TA03_160AlCu_nn.sdt
	130719	Strout	1	160	4.35	1.943	1.905	8 [2.8s]	LC_TA03_130719_160AlCu1slit	LC_TA03_160AlCu1slit_nn.sdt

Dark current, mid-range, bright field and I_o

Root Data Path:

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\LC_TA03_130719\Test_Data\{sub directory}\

Slits	kV	Filter	{sub directory}	Dark Image File Name	Mid-Brightness Image File Name	Max Brightness Image File Name	I_o Image File Name
2	100	Al	LC_TA03_130719_100Al	LC_TA03_100AldrkR.sdt	LC_TA03_100AlmidR.sdt	LC_TA03_100AllitR.sdt	LC_TA03_100Albak.sdt
2	160	AlCu	LC_TA03_130719_160AlCu	LC_TA03_160AlCudrkR.sdt	LC_TA03_160AlCumidR.sdt	LC_TA03_160AlCulitR.sdt	LC_TA03_160AlCubak.sdt
1	160	AlCu	LC_TA03_130719_160AlCu1slit	LC_TA03_160AlCu1slitdrkR.sdt	LC_TA03_160AlCu1slitmldR.sdt	LC_TA03_160AlCu1slitlitR.sdt	LC_TA03_160AlCu1slitbak.sdt

¹ nn - is the CT angular index number (0 through 399) for each individual data file

Reconstruction

Reconstructed by: Stephen A. Strout
Date: 7/19/2013
Location: LLNL
Computer: Dell Precision 690

Reconstruction Software

Software: IMGREC

Version: 2.8.1.1c11

Beam hardening compensation: Only for 100 kV Al filtered data using Al and H₂O reference materials for compensation.

Script Files

LLNL_script_LC_TA03_100Al.txt
 LLNL_script_LC_TA03_160AlCu.txt
 LLNL_script_LC_TA03_160AlCu1slit_tw_WDB.txt
 LLNL_script_H2OBHC_LC_TA03_100Al.txt

Reconstructed Specimen Files

Root Data Path:

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\LC_TA03_130719\Reconstruction\
 Recon_130719\{sub directory}\

Slits	kV	Filter	{sub directory}	Reconstruction file name
2	100	Al	LC_TA03_130719_100Al	recobj_nn ¹ .sdt
2	100	Al	H2O_Recon\LC_TA03_130719_100Al	recobj_nn.sdt
2	160	AlCu	LC_TA03_130719_160AlCu	recobj_nn.sdt
1	160	AlCu	LC_TA03_130719_160AlCu1slit	recry_nn.sdt , ry_nn.sdt

Observations:

¹ nn - is the index number for each reconstruction file, modified by an offset corresponding to the frame subsection extracted and analyzed.

Analysis

Analysis by: Isaac Seetho

Date: 7/19/2013

Location: LLNL

Computer: Dell Precision T7500

Analysis Software

Software: MATLAB

Version: R2010b

GUI Function/Script Files

micro_ct_gui_1_3.m¹

custrip_gui_split.m

Reference & Specimen Analysis Files

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\LC_TA03_130719\Analyses\LC_TA03_130719_analysis_IMS_130719\

Analysis File	LC_TA03_130719_characterization.xlsx
---------------	--------------------------------------

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\LC_TA03_130719\Analyses\LC_TA03_130719_H2O-BHC_analysis_IMS_130719\

Analysis File	LC_TA03_130719_H2O-BHC_characterization_Corrected.xlsx
---------------	--

Copper Strip Analysis Files

Root Data Path:

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\LC_TA03_130719\Analyses\LC_TA03_130719_custrip_IMS_130719\

Aggregate Statistics	Stats_LC_TA03_130719_W80xH7.xls
Mean Value Time Series	Custrip_LC_TA03_130719_W80xH7.xls

¹ Analysis using the MicroCT GUI is done according to the steps outlined in reference [7].

REFERENCES

1. Jeffrey S. Kallman, Daniel J. Schneberk, Harry E. Martz, Jr., *Two-energy Ratio Method to Determine Zeff from Reference Materials: A Comparison of an Explosive and a Simulant*, Version 3, Lawrence Livermore National Laboratory, LLNL-TR-491153, June 24, 2011.
2. Stephen Azevedo, Jeffrey S. Kallman, Harry E. Martz, Jr., *TP79 – Microstructure Studies Using MicroCT and EDS for DHS R&D*, Lawrence Livermore National Laboratory.
3. Isaac M. Seetho, Kenn E. Morales, W. Travis White, III, Harry E. Martz, Jr., *Summary Statistics for LC_TA01_130709: Micro-CT Data Acquired at LLNL, Specimen 1 of 3*, Lawrence Livermore National Laboratory, LLNL-TR-655005, December 13, 2013.
4. Isaac M. Seetho, Kenn E. Morales, W. Travis White, III, Harry E. Martz, Jr., *Summary Statistics for LC_TA02_130710: Micro-CT Data Acquired at LLNL, Specimen 2 of 3*, Lawrence Livermore National Laboratory, LLNL-TR-655000, December 13, 2013.
5. “Standard Operating Procedure — Industrial Computed Tomography System Data Collection of Home-Made Explosives,” U.S. Department of Homeland Security Science and Technology Directorate, DHS/STD/TSL-xx-xx, July 9, 2009.
6. Jerel A. Smith, Daniel J. Schneberk, Jeffrey S. Kallman, Harry E. Martz, Jr., David Hoey, *Documentation of the LLNL and Tyndall Micro-Computed-Tomography Systems*, Version 091216, Lawrence Livermore National Laboratory, LLNL-TR-421377, December 17, 2009.
7. Isaac Seetho, *MicroCT: Analysis of CT Reconstructed Data of Home Made Explosive Materials Using the Matlab MicroCT Analysis GUI*, Lawrence Livermore National Laboratory, IDD-MCT-SOP-007, January 13, 2011.
8. Harry E. Martz, Jr., and Carl Crawford, *Validation of Explosive Simulants Requirement Specification*, Version 12, Lawrence Livermore National Laboratory, LLNL-TR-416983-REV 1, October 26, 2009.
9. B. W. Silverman, *Density Estimation*, Chapman and Hall, 1986.